

Image-Based Wall Shear Stresses Calculations in Cartilage Endplate Explants and Scaffolds in Perfusion Culture

INTRODUCTION

The cartilage endplate (CEP) is a thin layer of cartilage that separates the intervertebral disc (IVD) from the vertebral body. It is the main gateway for nutrients and waste of the nucleus pulposus, thus playing a crucial role in keeping the IVD healthy. A key mechanical property is wall shear stresses (WSS) that has an influence on growth, differentiation, migration, and ECM production of the cells embedded in the CEP. This in turn would also affect the morphology, orientation, metabolic activities, and homeostasis of these cells by activating mechanotransducers that regulate gene expression and protein synthesis. Hence, replicating physiologically relevant WSS levels during cell culture might be beneficial. Here, we propose an *in silico* tool to quantify CEP WSS in explants and scaffolds during perfusion bioreactor experiments.

METHODS

The inputs for this *in silico* tool are CT scans, pressure drop, and fluid viscosity. It returns inlet and outlet velocities with respect to time and WSS at the simulation's last time point, either at steady state or after a preassigned duration. The tool assumes laminar flow due to the small diameter of pores inside the explant and scaffold but could be changed. In a first step, 3D-slicer was used to create the model of the sample, after which MeshLab was run to refine the model before sectioning it into inlet, outlet, and walls. Subsequently, OpenFoam is used, meshing the model using localized mesh controls to fine-tune the transition using SnappyHexMesh and then running the computational fluid dynamics analysis using a steady-state solver for incompressible flow following the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm.

The tool was tested on both bovine tail CEP explants and additively manufactured calcium-phosphate based scaffolds with well-defined parametric and morphological characteristics. The explants were taken from different bovine tails at different locations and CT scanned before being fitted into the perfusion bioreactor set-up. After fitting into silicon tubes, DMEM was run through the explants under defined pressure differences and the fluid flow rate was recorded. The additively manufactured scaffolds were CT scanned to have the as-produced geometries for the WSS calculations.

RESULTS

Passing fluid through a CEP purely under gravitational forces, leads to low WSS throughout the explant, mostly under 0.02 Pa. On the other hand, with the same pressure differences, the scaffold simulation showed WSS reaching to, on average, around 20 Pa. This difference in WSS is due to the faster fluid velocity experienced with the scaffold compared to the explant, resulting from the difference in porosity.

DISCUSSION

According to Salinas et al., the optimal range of fluid-induced WSS for chondrocytes is 0.05-0.21 Pa. This means that raising the pressure drop along the CEP explant and lowering it along the scaffold would generate more biologically relevant situations, both of which can be done using a controlled pump. The tool presented here enables the calculation of stresses present inside 3D porous biological and artificial tissues during perfusion culture, allowing a quantification of the required fluid flow rates in bioreactor set-ups to mimic physiological conditions in cell culture.